AERIAL ELECTROSTATIC SPRAY SYSTEM PERFORMANCE

I. W. Kirk, W. C. Hoffmann, J. B. Carlton

ABSTRACT. *Production models of a USDA–developed aerial electrostatic spray application system are currently being marketed in the US and abroad. Spray deposit and insect mortality studies conducted on cotton with the USDA prototype are summarized. Spray deposits with the electrostatic system were higher than with conventional aerial application systems. The increased deposits with the electrostatic system did not always produce improved insect control. Generally, the aerial electrostatic system with a spray rate of 9.4 L/ha provided similar insect control in these studies as conventional aerial spray systems with spray rates of 46.8 L/ha or aerial ULV spray systems with spray rates of 1 L/ha. Lower spray rates contribute to improved operational efficiencies for aerial applicators.*

Keywords. *Aerial sprays, Aircraft, Nozzles, Electrostatic, Spray, Droplets, Agricultural chemicals.*

Electrostatic principles have been employed successfully in applications for enhanced on–target and reduced off–target deposition of sprays. Industrial applications of paint and other coatings are notable examples (Colbert, 1982). Electrostatics has also been adapted to agricultural application of crop production and protection materials (Bowen et al., 1952; Bowen et al., 1964; Law, 1977; Law and Lane, 1981). Successful commercial versions of electrostatic sprayers for greenhouse, ground, and orchard sprayers have been available for several years (Sherman and Bone, 1983; Matthews, 1989; Kabashima et al., 1995; Palumbo and Coates, 1996; Brown et al., 1997; Sumner et al., 2000). Aerial electrostatic application has also been a subject of research and development (Carlton and Isler, 1966; Threadgill, 1973; Inculet and Fischer, 1989). But until recently there was no commercial adaptation of electrostatics to aerial applications. Research and development over an extended period (Carlton, 1968; Carlton, 1975; Carlton et al., 1995a) culminated in a patent (Carlton, 1999) for an aerial electrostatic application system that is currently marketed by Spectrum Electrostatic Sprayers, Inc. (Dobbins, 2000). Several field performance and efficacy studies were conducted in conjunction with design and development of this aerial electrostatic system.

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OBJECTIVE

The objective of this work is to document performance of the aerial electrostatic system from various field and laboratory studies with the research prototype that was the basis of the commercial version of the aerial electrostatic spray system.

MATERIALS AND METHODS

Prototype aerial electrostatic spray nozzles (fig. 1) and an associated charging system (Carlton, 1999), mounted on a Cessna T188C AgHusky agricultural aircraft (231 kW, 12.74–m wingspan), were the subject of field evaluations over a design and development span of five years. The ultimate prototype was composed of 88 electrostatic nozzles with TX–VK6 orifices (Spraying Systems Co., Wheaton, Ill.), calibrated for 9.4 L/ha at 483 kPa, and bipolar charging with inboard nozzles on each boom separated by 1.8 m. Conventional aerial application comparisons were made with the same aircraft with either 32 CP nozzles (CP Products Co., Inc., Tempe, Az.) calibrated for 46.8 L/ha at 193 kPa or a ULV application arrangement of 10 to 13 8002SS nozzles (Spraying Systems Co., Wheaton, Ill.) calibrated for 0.9 to 1.2 L/ha at 276 kPa.

Elements of selected field spray deposition and efficacy studies are presented to document typical aerial electrostatic system performance. The studies were conducted on cotton for whitefly and boll weevil control. Field studies routinely included sampling for spray deposit parameters and target pest mortality in field measurements or laboratory bioassays on field–treated leaves. Spray droplet deposit samples were collected on six water–sensitive paper (WSP) or oil–sensitive paper (OSP) cards (Spraying Systems Co., Wheaton, Ill.) at multiple replication or sample locations. Droplet stains on these cards were analyzed by image analysis procedures outlined by Stermer et al. (1988) and Franz (1993). Spray deposits on plant leaves were quantified either by dye fluorometry or gas chromatography. Caracid brilliant flavine FFS (Carolina Color and Chemical Co., Charlotte, N.C.) at rates of 12.4 and 25.7 g/ha was used as a dye tracer in these studies.

Typically, six to 10 leaves were collected in individually marked plastic bags at multiple replication or sample loca

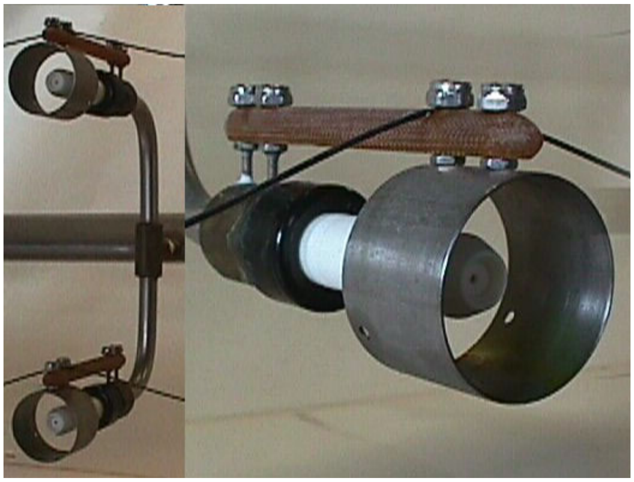

Figure 1. Aerial electrostatic spray nozzle. Inset shows nozzles mounted in pairs on spray boom.

ions in the treated areas on each sample day. The bags were placed in light–tight coolers and transported to the laboratory for analysis. Ethanol (20 ml) was pipetted into each bag, the bag was agitated, and an aliquot of rinsate was poured into fluorometer or GC vials. Leaves were removed from the bags and leaf areas were measured on a Li–Cor LI 3100 Area Meter (Li–Cor, Lincoln, Neb.) so deposits per unit area could be assessed. Dye tracer rinsates were analyzed with a Shimadzu RF5000U Spectrofluorophotometer (Shimadzu Corporation, Kyoto, Japan). Chemical active–ingredient rinsates were analyzed with a Hewlett–Packard 6890 gas chromatograph (Hewlett– Packard Company, Wilmington, Del.) with flame ionization and a J&W DB–1 dimethylpolysiloxane column (30 m × 0.32 mm × 0.25 μm) with a 2–ml/min flow of helium. The chromatograph and auto–sampler were operated with Hewlett–Packard's Chemstation software.

Operating parameters for malathion analyses were: injector temperature = 120°C and detector temperature = 250°C. The oven program was initiated at 60°C, which was held for 2 min. The temperature was then increased 30°C/min to 220°C, followed by a 5°C/min increase to 230°C, and subsequently followed by a 35°C/min increase to 300°C, which was then held for 2 min. Retention time for malathion was 9.08 min. The oven was allowed to cool before the next sample was injected.

The charge/mass ratio (Q/M) for the electrostatic spray nozzle with the different spray mixes was assessed in an agricultural aircraft spray nozzle test facility, previously described by Bouse and Carlton (1985) and Bouse (1994). The instrumentation to measure Q/M was described by Carlton (1999).

Mortality assessments for whitefly were made by in–field post–treatment counts of whitefly adults by the leaf turn method at 2, 4, and 6 days after sprays were applied (Naranjo and Flint, 1995). Populations of whitefly eggs and nymphs were determined by leaf–plug counts (Latheef et al., 1993). Bioassay mortality assessments for boll weevil were made on field–treated leaves collected on 0, 3, and 6 or 7 days post–treatment. Typically, six top–canopy leaves were collected at random from each replicated treatment area on each sample day, placed in paper bags, and transported to the laboratory. Equal numbers of leaves from untreated leaves in adjacent plots or fields were collected for checks. Individual leaves were placed in 10.2–cm–diameter, 1.2–cm–deep petri dishes. The whole leaves were placed on top of 10–cm–diameter moistened paper towels, ten USDA GAST Facility weevils were placed on the leaves, and the dishes were covered with petri dish covers. Covered dishes were maintained at 27°C on laboratory bench tops. Weevil mortality was counted 24 h after placement. Percent mortality compared to check samples was computed by the Abbott (1925) procedure.

Whitefly Management on Cotton

A season–long integrated management program for silverleaf whitefly (*Bemisia argentifolii*) on cotton was conducted at the University of Arizona, Maricopa Agricultural Center, Maricopa, Arizona, in 1995 (Carlton et al., 1995b; Latheef et al., 1995). Tank mixes of recommended active ingredient rates of endosulfan plus amitraz, fenpropathrin plus acephate, bifenthrin plus acephate, and esfenvalerate plus profenofos were each used according to state recommendations (Dennehy et al., 1995) at selected times during the season. Aerial electrostatic applications in spray rates of 4.7 L/ha were compared with conventional aerial applications in spray rates of 46.8 L/ha. The charge/mass ratio (Q/M) for the electrostatic applications was typically ±1.15 mC/kg. Applications were initiated and repeated at least weekly when whitefly counts reached threshold levels of 5 adults per leaf. Spray deposits were washed from leaves with a leaf washer (Carlton, 1996).

Fipronil for Control of Boll Weevil on Cotton

Three aerial applications of label rates of fipronil on cotton were made in: (1) 9.4 L/ha of water with the electrostatic spray system, and (2) 0.9 – 1.2 L/ha vegetable oil with an aerial ULV application system. ULV malathion at 0.9 L/ha was applied along with the fipronil treatments in four blocks under an experimental use permit on the Texas A&M University Farm (Kirk et al., 2000a). The Q/M for the electrostatic fipronil treatment was typically ±1.37 mC/kg. The fipronil in oil and ULV malathion treatments were made according to protocol outlined by the Texas Boll Weevil Eradication Foundation (TBWEF) (Myers, 1995). Caracid brilliant flavine FFS dye tracer (Carolina Color and Chemical Company, Charlotte, N.C.) was dissolved in methanol (33 mL/ha) and used in all spray mixes.

EC Malathion 5 for Control of Boll Weevil on Cotton

Four aerial applications of electrostatic EC Malathion 5 in 9.4 L/ha water and ULV malathion at 0.95 L/ha were made in two field replications, each at 1.12 kg/ha malathion (Kirk et al., 2000b). Applications were made on commercial cotton fields in Robertson County, Texas. The Q/M for the electrostatic malathion treatment was typically ±1.07 mC/ kg. The ULV malathion treatments were made according to protocol outlined by TBWEF.

Results

Whitefly Management on Cotton

Leaf deposits of fluorescent dye on top and mid–canopy leaves averaged over the season were significantly higher for the electrostatic application as compared to the conventional application, at 34.5 and 29.6 ng/cm^2, respectively ($\alpha = 0.05$). Numbers of whitefly adults counted on cotton leaves post–

treatment averaged 3.6 and 3.9 through mid–season and 5.0 and 5.5 through the entire season for electrostatic and conventional applications, respectively, but were not significantly different. Whitefly egg counts on leaf plugs averaged 15.0 and 10.6 for electrostatic and conventional applications, respectively, but were not significantly different. Large nymph counts on leaf plugs averaged significantly higher for the electrostatic applications than for the conventional applications, 3.7 and 2.1, respectively ($\alpha = 0.05$).

Fipronil for Control of Boll Weevil on Cotton

Dye deposits on top canopy leaves averaged 24.7, 36.1, and 11.8 ng/cm^2, respectively, for the electrostatic fipronil, ULV malathion, and fipronil in oil treatments. Weevil mortalities in laboratory bioassays were highly variable. There were significant interactions between treatment dates and days after spraying that did not appear to be related to observed phenomena. The electrostatic fipronil and ULV malathion treatments both gave above 95% weevil mortality on the day of spray application (table 1). Weevil mortality from the fipronil in oil treatment was lower than that for the other two treatments on days 0 and 3 after spraying. Electrostatic applications of fipronil gave significantly higher weevil mortalities than the ULV malathion treatment on day 3 after spraying. Effectiveness of the three treatments had dropped to 2% or less by day 7 after treatment application.

EC Malathion 5 for Control of Boll Weevil on Cotton

Malathion deposits on top canopy leaves averaged 6.33 and 5.85 ng/cm^2 for the electrostatic and ULV applications, respectively. There was a significant interaction between treatments and sampling day after spray application for percent boll weevil control (table 2). The electrostatic EC Malathion 5 treatment had higher mortality on the day of application than the ULV malathion treatment, but significantly lower mortalities on days 3 and 6 after spray application. Boll weevil mortality for ULV malathion dropped significantly on days 3 and 6 after spray application, but did not drop as much as observed for the electrostatic EC Malathion 5 treatment.

Table 1. Percent boll weevil mortality compared to a check in laboratory bioassays for fipronil and malathion treat– ments for three periods after spray application[a].

Days after application	Electrostatic fipronil	ULV malathion	Fipronil in oil
0	96.6a	95.5a	76.7b
3	50.2c	33d	18.4e
7	1.9f	2.0f	1.4f

[a] Means followed by the same letter are not significantly different by Fisher's Protected $LSD_{0.05}$.

Table 2. Percent boll weevil mortality compared to a check in laboratory bioassays for two malathion treatments for three periods after spray application[a].

Days after application	Electrostatic EC malathion 5	ULV malathion
0	97.0a	88.7b
3	29.8e	56.1c
6	29.0e	43.1d

[a] Means followed by the same letter are not significantly different by Fisher's Protected $LSD_{0.05}$.

Summary and Discussion

Interest in electrostatic charging of agricultural sprays has persisted since the concept was first introduced. Laboratory demonstrations of increased deposits and wraparound coverage with electrostatically charged sprays are dramatic, but field results have not always been so impressive. However, the potential for increased spray deposits, underside leaf deposition, and associated reduced active ingredient requirements have spurred researchers to continue developmental efforts. Maintenance of adequate Q/M has been an obstacle for aerial electrostatic system development because of spray system flow rates required for normal aircraft speeds and swath widths. The present aerial prototype system compromises higher Q/M to achieve a 9.4 L/ha spray rate, which is the minimum spray rate specified on product labels for many pesticides. However, this trade–off presents an additional benefit for aerial electrostatic systems because low spray rates permit more area to be treated with a single hopper load, thus increasing overall aerial operational efficiency.

Electrostatic charging of sprays with the aerial prototype system increased deposits of tracer dye on cotton leaves in the whitefly management study where the comparison was with conventional aerial spray rates. Electrostatic system deposits of tracer dyes and active ingredients as compared to ULV applications of malathion were mixed; tracer dye deposits with the electrostatic system in the fipronil study were lower than dye deposits with the ULV malathion system, but active ingredient deposits were higher in the malathion study with the electrostatic system than with the ULV system. These differences may be attributable to differences in application conditions or undetermined properties of the fipronil spray mix. The fipronil spray mix was expected to deposit preferentially because of the higher Q/M ratio.

Mortality data in the whitefly study indicate that adults were more effectively controlled with the electrostatic applications than with conventional applications. However, there was a trend for higher numbers of whitefly eggs in plots treated with the electrostatic system. Whitefly nymphs were more effectively controlled with conventionally applied higher spray rates. Other studies have shown that spray application and deposit parameters can be optimized for different pests or life forms of the same pest. In this study, the electrostatic sprays were more effective on the adult than the immature stages of the whitefly.

The fipronil study was conducted because the product was suggested as an alternative toxin for use in boll weevil eradication programs. In addition, survey studies of electrostatic charge/mass ratios for various insecticides had shown that fipronil accommodated a higher Q/M than most other insecticides. Electrostatic fipronil and ULV malathion both caused high boll weevil mortality in laboratory bioassays on the day sprays were applied. Three days after the sprays were applied, electrostatic fipronil caused significantly higher boll weevil mortality than ULV malathion. The results for ULV malathion are not consistent with boll weevil mortalities observed in the study of electrostatic EC malathion vs. ULV malathion. Conse– quently, speculation on increased persistence of electrostatic fipronil may be unwarranted.

The electrostatic EC malathion study showed electrostatic application of EC malathion gave better boll weevil mortality than ULV malathion on the day sprays were applied. The persistence of electrostatic EC malathion, in terms of boll weevil mortality, dropped significantly on days 3 and 6 after spray application compared to ULV malathion. However, the inconsistent performance of ULV malathion in the two studies has a bearing on these observations.

CONCLUSIONS

These studies show some situations where field performance of the aerial electrostatic spray system exceeds that of conventional systems, and vice versa. That is neither unusual nor unexpected. Most application technologies have niches in which they are best adapted. However, in general terms, aerial electrostatic application methodology has been shown to have spray deposits and efficacies that are not markedly different from conventional aerial application methodologies. Other factors, such as operational efficiencies associated with the low spray rates of electrostatic systems, could be an important factor favoring aerial electrostatic applications.

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REFERENCES

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. *J. Econ. Entomol.* 18: 265–267.

Bouse, L. F. 1994. Effect of nozzle type and operation on spray droplet size. *Trans. ASAE* 37(5): 1389–1400.

Bouse, L. F., and J. B. Carlton. 1985. Factors affecting size distribution of vegetable oil spray droplets. *Trans. ASAE* 28(4): 1068–1073.

Bowen, H. D., P. Hebblethwaite, and W. M. Carleton. 1952. Application of electrostatic charging to the deposition of insecticides and fungicides on plant surfaces. *Agric. Eng.* 33(6): 347–350.

Bowen, H. D., W. E. Splinter, and W. M. Carleton. 1964. Theoretical implications of electrical fields on deposition of charged particles. *Trans. ASAE* 7(1): 75–82.

Brown, J. R., D. C. William, R. O. Melson, and T. Gwinn. 1997. An electrostatic backpack sprayer: Potential for mosquito control. *J. Am. Mosquito Control Assoc.* 13(1): 90–91.

Carlton, J. B. 1968. Techniques in electrostatic charging of sprays from aircraft. In *Proc. 17th Annual Texas Agric. Aviation Conf. and Short Course on Pest Control*, G1–G19. 25–27 February. College Station,Texas. Texas A&M University.

_____. 1975. Electrical capacitance determination and some implications for an electrostatic spray–charging aircraft. *Trans. ASAE* 18(4): 641–644.

_____. 1996. Dual side plant leaf washer and immersion cell. U.S. Patent No. 5,503,005.

_____. 1999. Technique to reduce chemical usage and concomitant drift from aerial sprays. U.S. Patent No. 5,975,425.

Carlton, J. B., and D. A. Isler. 1966. Development of a device to charge aerial spray electrostatically. *Agric. Aviation* 8(2): 44–51.

Carlton, J. B., L. F. Bouse, and I. W. Kirk. 1995a. Electrostatic charging of aerial spray over cotton. *Trans. ASAE* 38(6): 1641–1645.

Carlton, J. B., I. W. Kirk, and M. A. Latheef. 1995b. Cotton pesticide deposition from aerial electrostatic charged sprays. ASAE Paper No. AA95–007. St. Joseph, Mich.: ASAE.

Colbert, J. C., ed. 1982. Modern coating technology: Radiation curing, electrostatic, plasma, and laser methods. *Chem. Technol. Rev.* 0198–6880 No. 201. Park Ridge, N.J.: Noyes Data Corp.

Dennehy, T. J., P. C. Ellsworth, and R. L. Nichols. 1995. Whitefly management in Arizona cotton. IPM Series No. 3. Tucson, Ariz.: University of Arizona, College of Agriculture.

Dobbins, T. 2000. Texas aerial applicator tries electrostatic spray system. *AgAir Update* 18(5): 24–25.

Franz, E. 1993. Machine vision using image gradients for spray–deposit analysis: Software development. *Trans. ASAE* 36(6): 1955–1965.

Inculet, I. I., and J. K. Fischer. 1989. Electrostatic aerial spraying. *IEEE Transactions on Industry Applications* 25(3): 558–562.

Kabashima, J., D. K. Giles, and M. P. Parrella. 1995. Electrostatic sprayers improve pesticide efficacy in green houses. *Calif. Agric.* 49(4): 31–35.

Kirk, I. W., S. J. Harp, and A. M. Wiese. 2000a. Aerial sprays of fipronil for control of boll weevil. In *Proc. Beltwide Cotton Conf.* 2: 1281–1283. Memphis, Tenn.: National Cotton Council of America.

Kirk, I. W., W. C. Hoffmann, and S. J. Harp. 2000b. Aerial electrostatic EC malathion 5 for boll weevil control. In. *Proc. Beltwide Cotton Conf.* 2: 1205–1207. Memphis, Tenn.: National Cotton Council of America.

Latheef, M. A., L. F. Bouse, and I. W. Kirk. 1993. Aerial sprays for control of sweetpotato whitefly in cotton: Efficacy. ASAE Paper No. AA93–005. St. Joseph, Mich.: ASAE.

Latheef, M. A., J. B. Carlton, and I. W. Kirk. 1995. Electrostatically charged aerial sprays for control of sweetpotato whitefly in cotton: Efficacy. ASAE Paper No. AA95–008. St. Joseph, Mich.: ASAE.

Law, S. E. 1977. Electrostatic spray nozzle system. U.S. Patent No. 4,004,733.

Law, S. E., and M. D. Lane. 1981. Electrostatic deposition of pesticide spray onto foliar targets of varying morphology. *Trans. ASAE* 24(6): 1441–1445, 1448.

Matthews, G. A. 1989. Electrostatic spraying of pesticides: A review. *Crop Prot.* 8(Feb): 3–15.

Myers, F. D. 1995. Solicitation for bid for 1995: Aerial application of insecticides. Solicitation No.: 0002TBWEF95. Abilene, Texas: Texas Boll Weevil Eradication Foundation, Inc.

Naranjo, S. E., and H. M. Flint. 1995. Spatial distribution of adult *Bemisia tabaci* (Homoptera: Aleyrodidae) in cotton and development and validation of fixed–precision sampling plans for estimating population density. *Environ. Entomol.* 24(2): 261–270.

Palumbo, J. C., and W. E. Coates. 1996. Air–assisted electrostatic application of pyrethroid and endosulfan mixtures for sweetpotato whitefly (Homoptera: Aleyrodidae) control and spray deposition in cauliflower. *J. Econ. Entomol.* 89(4): 970–980.

Sherman, M. E., and J. R. Bone. 1983. Electrodyn sprayer pesticide application using electrostatic atomization. In *ASTM Special Technical Publication 828*, 100–109. Conshohocken. Pa.: American Society for Testing and Materials.

Stermer, R. A., L. F. Bouse, J. B. Carlton, I. W. Kirk, and L. E. Bode. 1988. Comparisons of various techniques for measuring spray deposition. ASAE Paper No. AA88–001. St. Joseph, Mich.: ASAE.

Sumner, H. R., G. A. Herzog, P. E. Sumner, M. Bader, and B. G. Mullinix. 2000. Chemical application equipment for improved deposition on cotton. *J. Cotton Sci.* 4(1): 19–27.

Threadgill, E. D. 1973. Evaluation of aerial electrostatic spray charging equipment. Tech. Bulletin 65. Mississippi State, Miss.: Mississippi State University, Miss. Agric. and Forestry Experiment Station.